

ON THE VELOCITIES OF TWO DISTINCT GROUPS OF
SECONDARY CORPUSCULAR RAYS PRODUCED BY A
HOMOGENEOUS RÖNTGEN RADIATION, AND THEIR
ABSORPTION COEFFICIENTS IN VARIOUS GASES.

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(With six Text-figures.)

(Figs. 2, 3 and 5 are in the form of folding plates and are inserted
together at the end of the paper.)

PART I.

The emission of a so-called homogeneous corpuscular radiation from a metal plate during the incidence of Röntgen rays upon it has been studied in detail by Sadler* and Beatty.† By using homogeneous beams of Lenard rays Whiddington showed that the law expressing their velocity as a function of the depth of matter passed through could be written‡—

$$(i) \quad \dots v_o^4 - v_x^4 = ax,$$

the constant a depending upon the nature of the absorbing material, but no relationship could be traced between the value of a and the density or atomic weight of the absorbers. In a later paper§ he showed, from the experimental results of Sadler and Beatty, that the maximum velocity of the corpuscular rays ejected by a characteristic Röntgen radiation was proportional to the atomic weight of the radiator supplying the Röntgen rays, and that this maximum velocity was independent of the nature of the substance from which they were ejected. Barkla and Shearer|| have extended this result so as to include either the “K” or “L” cathode rays, their conclusion being that the maximum velocity of ejection of the particles, wherever be their source in the atom, is the same for the incidence of a given wave-length of Röntgen radiation.

The object of the work undertaken in this paper was twofold:

(1) To investigate the absorption coefficients of the secondary corpuscular rays in various gases.

* ‘Phil. Mag.,’ [6] xix, p. 337 (1910).

† *Ibid.*, [6] xx, p. 320 (1910).

‡ ‘Proc. Roy. Soc.,’ A, lxxxvi, p. 370 (1912).

§ *Ibid.*, p. 376.

|| ‘Phil. Mag.,’ [6] xxx, p. 753 (1915).

(2) To find, if possible, a velocity distribution, from the maximum downwards, of the particles about the radiator.

With regard to (1), a fairly complete summary of the work already done for the gases, air, and hydrogen is given in Kaye's 'X Rays,' 1917, whilst, in the case of (2), Richardson remarks. "The experiments hitherto made which bear on this point (that in general there will be other groups of electrons for which the maximum energy may in general have any value between $h\nu^*$ and zero) have been directed to the determination of the maximum energy of the whole group of electrons, and would not be expected to detect the simultaneous presence of groups having a less degree of maximum energy than that value."†

The experimental results of this paper were obtained during the first three months of 1918.

If there exists a velocity distribution of the electrons, then it must be noted that the absorption coefficients of Sadler and Beatty are mean values. The following points are noted :

- (1) The electrons are emitted from the plate initially in every direction.
- (2) The maximum distance they can travel in air at normal pressure is a few millimetres, this being the length of the track of gaseous ions each produces by bombardment. These tracks are very irregular in shape.
- (3) The initial speed of ejection conforms approximately to Whiddington's law, $v_s = kw$, where k is a constant and w the atomic weight (more probably twice the atomic number) of the radiator supplying the Röntgen rays.
- (4) The ionisation per cm. of the path of each electron is proportional to its fall of kinetic energy per cm. which is governed by equation (i).
- (5) The only method of arriving at an absorption coefficient in a gas, if absorption coefficient in this respect has any meaning, is by measuring, directly or indirectly, the number of secondary gaseous ions produced at different distances from the plate emitting the original electrons.

As early as 1895 Lenard showed that λ/d was practically constant for both gaseous and solid substances (λ is the logarithmic absorption coefficient and d the density of the absorber) for cathode particles emerging from a window of aluminium in a discharge tube. He showed that the absorption coefficient *was* logarithmic, and it measured the change in energy of the cathode particles in their passage through matter. Friman‡ has shown that when the error for diffusion has been allowed for, the absorption coefficient of the fast-moving β -rays from uranium-X in oxygen, carbon dioxide, and the vapour of acetone is approximately proportional to the

* $h\nu$ = the quantum of characteristic Röntgen radiation which falls on the plate emitting the electrons.

† 'Proc. Roy. Soc.,' A, xciv, p. 272 (1918).

‡ 'Ann. der Physik,' xlix, 4, p. 373 (1916).

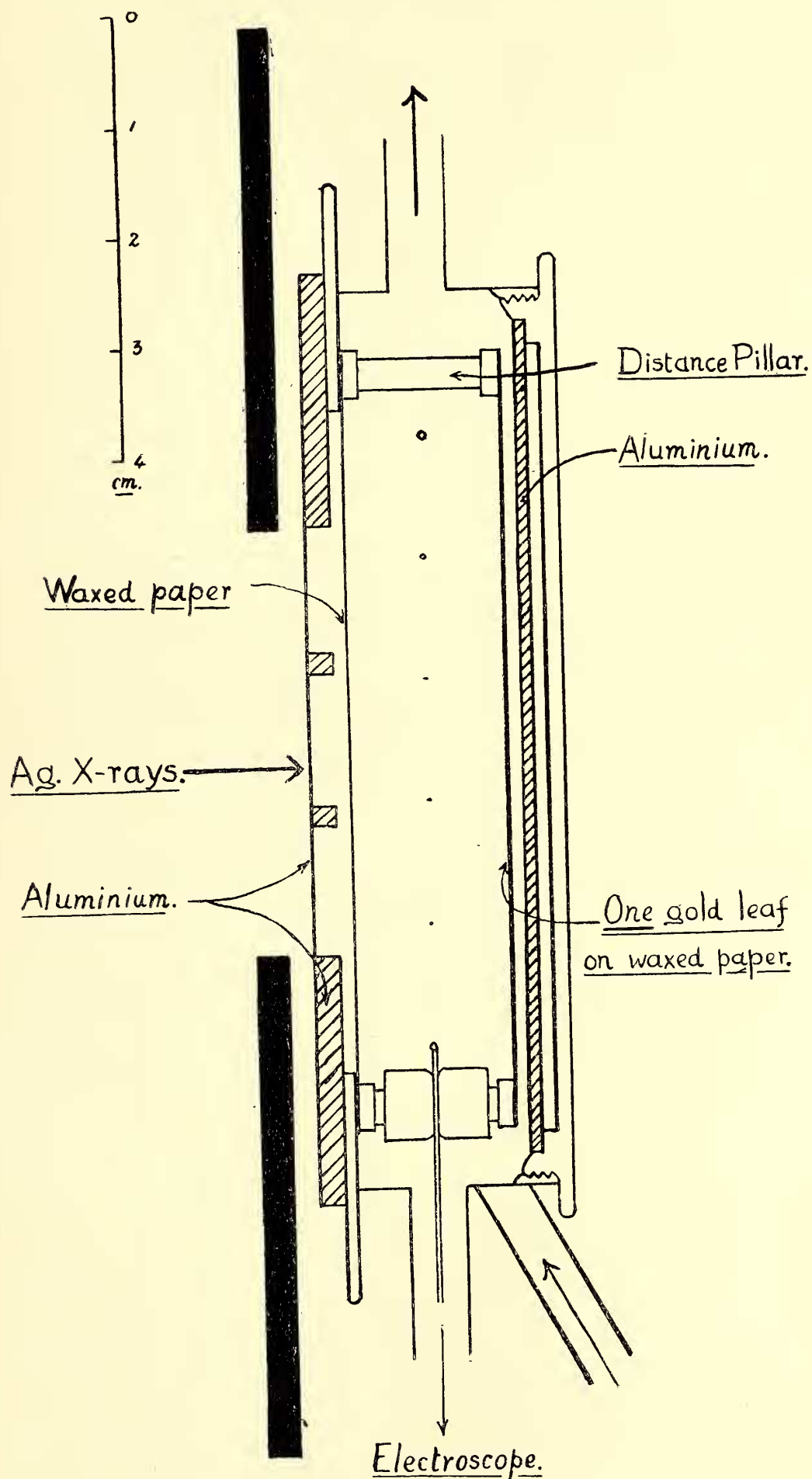


FIG. 1.

density of these substances. In more complex substances there is a marked deviation from proportionality.

The method employed in this work for the determination of the absorption coefficients of the corpuscular rays in various gases was the "pressure variation" method used by Beatty. The gases used were air, O_2 , CO_2 , SO_2 , which were passed slowly through a shallow ionisation chamber, a section of which is given in Fig. 1. The gas pressure could be varied from approximately zero up to atmospheric pressure, and the ionisation measured with an ordinary Wilson electroscope. The quantity of radiation falling into the chamber was standardised in the usual way with a standardising electroscope, and as silver X rays were used throughout, a screen of aluminium $\cdot 075$ cm. thick was placed in the path of the beam of X rays before it entered the chamber in order to eliminate the very easily absorbed L-radiation from the silver plate. Two complete sets of experiments were performed, giving the two sets of curves shown in Fig. 2. In the upper four, using the four gases successively at various pressures, the silver X rays fell on a sheet of gold leaf stuck on a sheet of waxed filter-paper which backed the chamber. In the lower four the conditions were precisely the same, except that the gold leaf was now absent. The ordinary "reflection" method was employed for obtaining a homogeneous beam.

The ionisation chamber possessed two unique features. The first was the electrode, which was a grid of about 2 cm. mesh of new, very fine carbon filament used in electric lamps. This was charged to a potential of about 240 volts. The second was the thinness of the gold screen. Any attempt to detect a true velocity distribution of the cathode particles characteristic either of the incident X rays or of the absorbing screen would require an infinitely thin screen so as to eliminate the effects of particles emerging from deeper layers in it. Hence it was that only one gold leaf was employed at the back of the chamber. Its thickness was calculated to be $\cdot 000008$ cm. Using formula (i) we have, according to Whiddington, a (for gold) $= 2\cdot 54 \times 10^{13}$, $x = \cdot 000008$ cm., $v_0 = 108 \times 10^8$. On calculating v_x it is seen that the fall in speed of the fastest cathode particles, or of those having an initial velocity of, say, $\frac{1}{2}v_0$, will be inappreciable compared with their maximum initial velocities if they were generated at the back of the gold leaf and had to penetrate it in order to emerge into the ionisation chamber.

Preparation of the Gases.

Air.—Atmospheric air roughly dried by bubbling through strong H_2SO_4 .

Oxygen.—From the electrolysis of dilute H_2SO_4 . The ozone was removed by passing the gas through a glass tube immersed in a sand-bath kept at about $260^\circ C$. and then dried by passing through strong H_2SO_4 .

Carbon dioxide.—From commercial HCl and marble and dried with H_2SO_4 .

Sulphur dioxide.—From Johnson's "Pure Sodium Sulphite" and H_2SO_4 . Dried H_2SO_4 .

The gas flowed gently through the chamber and into a large vessel of about 10 litres capacity connected to its exit. This arrangement was to ensure that the gas in the chamber should be steadily replenished, but that the pressure within should not vary by more than a few millimetres of mercury during a run. The mean pressure was recorded.

The ordinates of the two curves for a given gas in Fig. 2 have been subtracted, giving the curves shown in Fig. 3. These curves represent the total ionisation produced in the gas at various pressures by the cathode particles from the gold leaf backing the chamber when silver X rays fall upon it.*

At this point it would not be out of place to indicate the manner in which the absorption coefficients have been obtained from the "cathode ionisation" curves in Fig. 3, as in the latter part of the paper the exact process has to be kept in mind.

Consider an instantaneous distribution of ions represented by Fig. 4 *b*. There is a critical pressure P at which, for a given initial speed of ejection, the ionising property of the least scattered cathode particle persists until the other side of the chamber is just reached. For this pressure let ρ_0 be the number of ions present per c.c. in a thin slab of gas next to the gold leaf. Next, assuming that the number of ions produced per c.c. from any cause be proportional to the density of the gas, then at a pressure $2P$ the density of ions at the gold radiator will be $2\rho_0$, but now the maximum distance traversed by the least scattered particles will be $t/2$. In other words, doubling the pressure halves the linear dimensions of the ionised track of each electron without altering the shape of the track, whatever that may be. The condition is represented by Fig. 4 *a*. Coming now to the case in which the pressure is $P/2$, the most normally directed electrons would ionise, were they not absorbed by the front face of the chamber, up to a maximum distance of $2t$ from the gold leaf, and the density of the ions at the gold leaf $= \rho_0/2$. The areas of all the curves are equal.

Reference to the cathode ionisation curves will show that condition (*b*) is represented by the point B on the air curve, (*a*) by A and (*c*) by C. In

* More strictly it is the ionisation by the cathode particles from the gold, less that by those emerging from a sheet of waxed paper, plus the ionisation in the gas by the tertiary X rays from gold and all the effects due to it. The lower set of curves in Fig. 2 shows that the ionisation in the gas due to the cathode particles emerging from a sheet of waxed paper can be neglected. If any did exist their properties would not differ greatly from those from gold. The ionisation effect due to any tertiary X rays from the gold leaf would be proportional to the pressure of the gas, and, as the curves in Fig. 3 show no variation in the ordinate beyond a certain critical pressure, this effect can also be neglected.

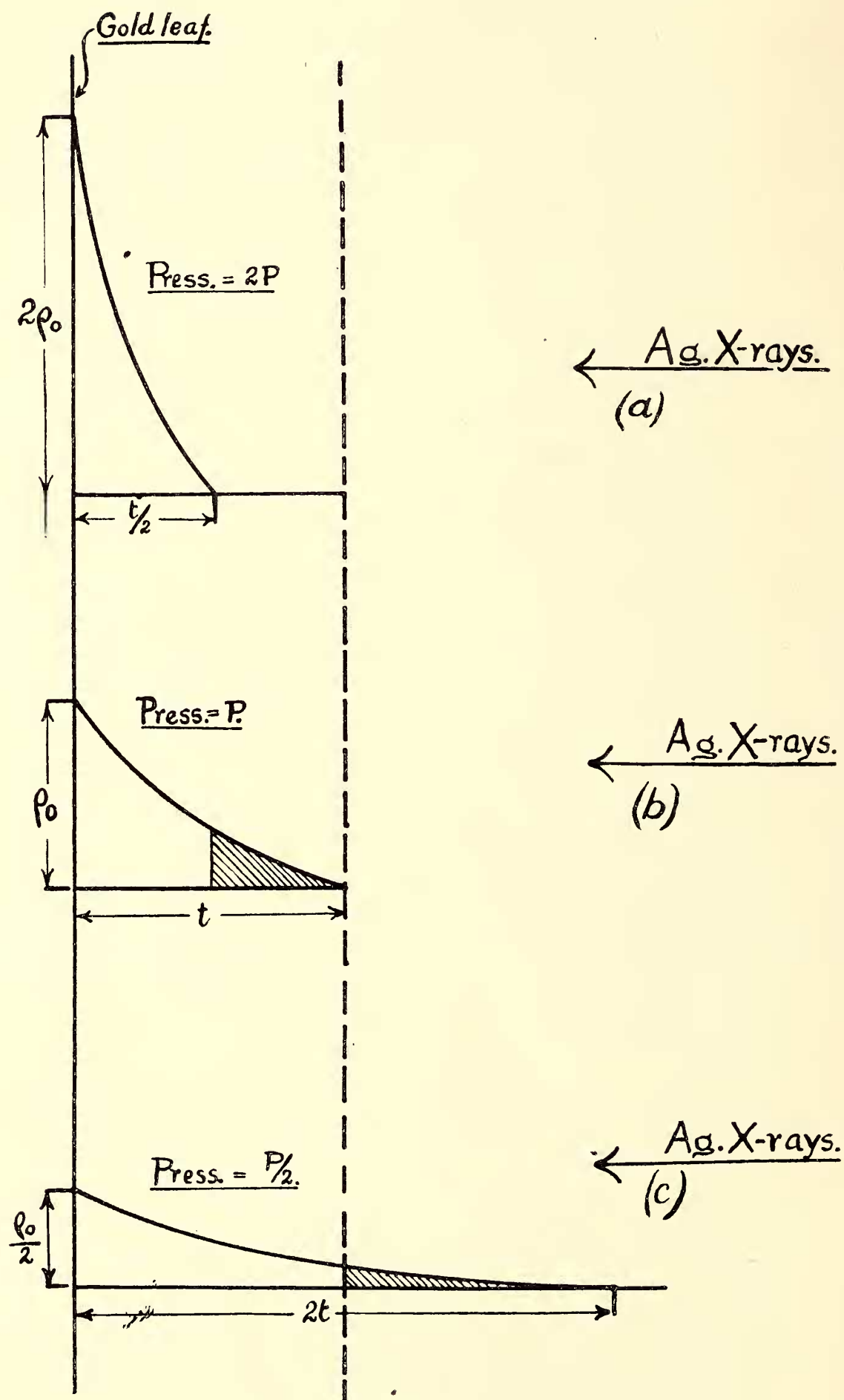


FIG. 4.

this last case the ions represented by the shaded toe are lost. This area equals that of the shaded toe of the curve Fig. 4, *b*.

It is to be remembered, however, that the ordinate on the cathode-ionisation curve at any given pressure p represents the area of the ionisation-density curve in Fig. 4 included between the two faces of the chamber. The ordinate CC' (Fig. 3) is a measure of the unshaded area in Fig. 4, *b*, and, therefore, if at the critical pressure the ionisation-density curve is given by—

$$\rho = \rho_o f(x)$$

then—

$$CC' = \rho_o \int_0^{t/2} f(x) dx = N_{t/2},$$

which equals the total number of ions existing at a given instant in a slab of half the thickness of the chamber, in this particular case.

It will be seen that $x = tp/P$ and that if the form of the function represented by the experimentally obtained cathode ionisation curve can be found, the first differential coefficient of this function gives the density distribution function of the ions across the chamber, with the possibility of determining the absorption coefficient.

First Approximation.

It will be seen from the figure that the cathode-ionisation curves proximate to $N_x = N_o(1 - e^{-\lambda x})$, and therefore the density ionisation in the chamber itself will be of the form $\rho = \rho_o e^{-\lambda x}$, where $\rho_o = N_o \lambda$ and λ is the absorption coefficient. If x be taken as the distance across the chamber at which the ionisation density becomes one-half of what it is at the gold screen, we obtain—

$$\lambda = \frac{\log_{10} 2}{x \times .4343} \quad \text{where } x = \frac{p_{\frac{1}{2}}}{P} \times 1.45 \text{ cm.},$$

since the depth of the chamber was 1.45 cm., P is the critical pressure for the gas in question, and $p_{\frac{1}{2}}$ that pressure at which one-half of the ions that could be produced by the cathode particles are missing through the electrons having been absorbed by the opposite wall of the chamber. It will be noted that the absorption coefficient so found will be that at a pressure P , and therefore—

$$\lambda \text{ at N.T.P.} = \frac{\log_{10} 2}{p_{\frac{1}{2}} \times 1.45 \times .4343} \times 76 \times \frac{273 + T}{273}.$$

It will be noticed that P is absent.

The results obtained in this manner are tabulated in Table I. I have put them in this form for comparison with Beatty's results for air and hydrogen.

TABLE I. (Beatty's Method.)

Absorption Coefficients in Various Gases of the Corpuscular Rays produced by Characteristic Silver X rays. $w.l. = .560 \times 10^{-8}$ cm.

Absorbing gas.	Total ionisation by complete absorption of corpuscular rays.	Values in column II relative to air = 1.	For comparison with column III.	$p\frac{1}{2}$ obtained from curves, fig. 3.	Mean temp.	λ at 0° C. and 76 cm.	Density (d).	λ/d .
H ₂	—	—	1, B. 1.02, B.P.	—	—	.80B*	.00009	8900
Air	.748	1	1	4.12 cm.	23° C	9.56	—	7410
						9.3, B†	.00129	7210
O ₂	.786	1.05	1.10, B.P.	3.46 „	26°	11.50	.00143	8040
CO ₂	.738	.99	1.02, B.P.	2.32 „	23°	16.97	.00198	8570
SO ₂	.88	1.18	.96, B.P.	2.30 „	22°	17.06	.00293	5820
Mean =								7660

B = Beatty, *loc. cit.*
B.P. = Barkla and Philpot, 'Phil. Mag.,' [6], June (1913).

The mean value of λ/d found by Lenard in two experiments on absorption in air, two in hydrogen and one in sulphur dioxide was 3774. This was for cathode rays having a speed given by a fall through 30,000 volts. By using the value for e/m and the relationship $V_K = 10^8 A$, where V_K is the above speed and A the atomic weight of the metal supplying the characteristic X rays which would produce this maximum speed, it was found that rhodium (at. wt. 103) is the approximate metal; it is known also that $\lambda A^4 = \text{constant}$. In this way I estimate that Lenard's constant would have been of the order 3120 had he used cathode rays excited by silver X rays. It appears, therefore, that the absorption coefficients in Table I are abnormally high.

It cannot be stated with certainty that Lenard's rays were homogeneous. The same is true of the rays employed in these experiments, as will appear from Part II of this paper.

* Estimated from $\lambda = .51$ at 15° C. for corpuscular rays from silver produced by Sn. X rays, using the relationship $\lambda (\text{at. wt.})^4 = \text{constant}$.
† Calculated from Beatty's value 8.8 at 15° C. for Ag. X rays falling on silver. Beatty corrected his values to 15° C. and 76 cm. pressure. Subsequent writers quote his figures as at 0° C. and 76 cm. pressure. See 'Phil. Mag.,' [6] xx, p. 323 (1910).

PART II.

It has been shown in Part I that the absorption coefficients of corpuscular rays in various gases, found by a method similar to that adopted by Beatty in 1910 for air and hydrogen, are probably too high. The reason becomes apparent from a critical examination of the cathode ionisation curves. It was stated that they proximated to the form $N_x = N_o (1 - e^{-\lambda x})$, which gives a logarithmic fall in the ionisation-density curve from the gold leaf backing the ionisation chamber, forwards. In this way a logarithmic absorption coefficient was found.

Plotting the logarithms of $N_o - N_x$ against x (or p) should result in a

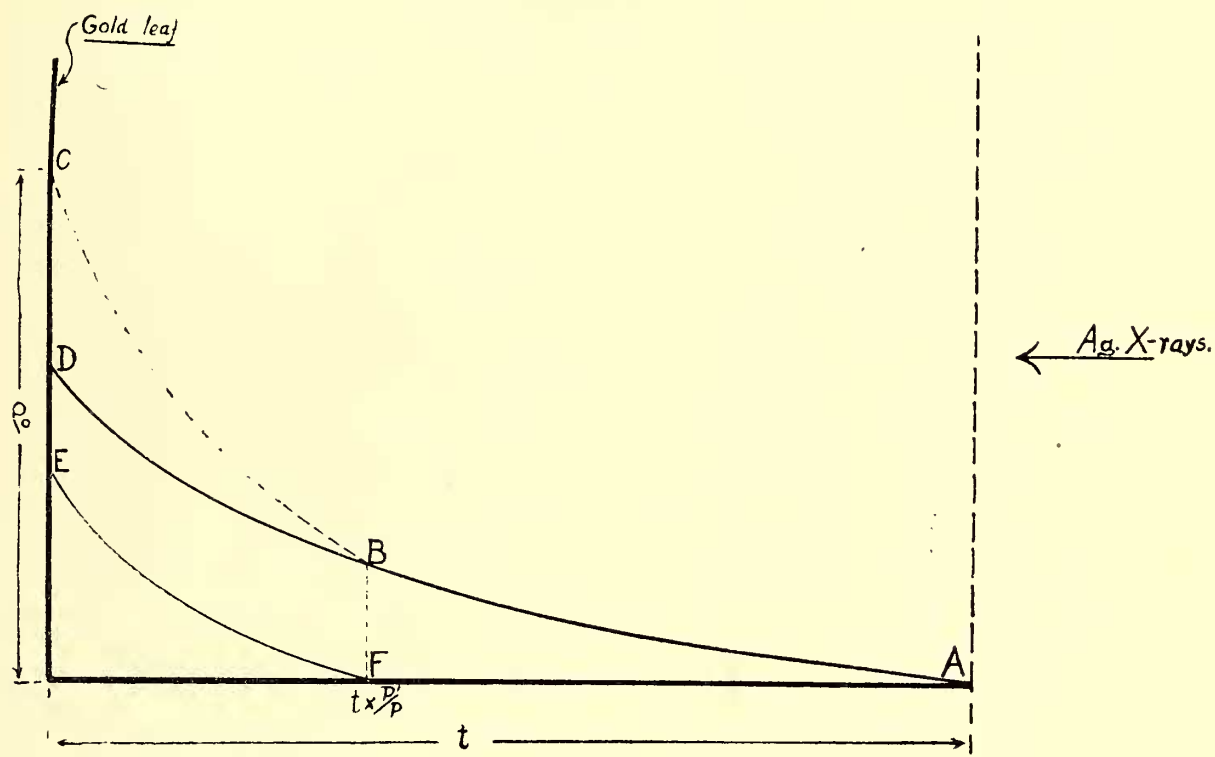


FIG. 6.

straight line. The cathode ionisation curves for the four gases were carefully drawn, and the logarithmic curves deduced from them are shown in Fig. 5. The departure of these curves from linearity is at once apparent; they are all concave upwards. On the air logarithmic curve, for example, a distinctly straight portion and a curved portion meet at B, and the curve shows no further tendency to “flatten out” beyond A. I therefore conclude that the slope of the line AB, which is perfectly straight, is a true measure of the absorption coefficient of the cathode particles and consequently a measure of their velocity. AB refers, however, to a faster group of particles, whilst CB refers to a slower group, as will be explained below. This latter group is completely absorbed in a distance $t \cdot \frac{P'_A}{P_A}$ at a pressure P_A , where this is the critical pressure for air for the faster group, P' , the pressure at B and t the depth of the ionisation chamber.

The corresponding ionisation-density curve is represented by the line CBA in Fig. 6, which is the summation curve of the two ionisation-density curves DBA and EF, corresponding to the ions produced by at least two distinct groups of corpuscles leaving the gold.

The method by which the logarithmic curve for the group of ions, whose ionisation-density curve is represented by EF (Fig. 6), was found, was to continue the line AB (Fig. 5) backwards, and to reconstruct from the antilogarithms the part of the curve BD (Fig. 6) which has its equivalent in OD in Fig. 3. The logarithm of the difference between this deduced cathode ionisation curve for the faster group and the experimentally obtained summation cathode ionisation curve for the two groups was again plotted against p (or x), giving the more sloping logarithmic curves in Fig. 5. Readings taken directly from these lines yield the following table of absorption coefficients :

TABLE II.
Showing that there are at least Two Distinct Groups of Particles ejected with Different Velocities from a Very Thin Gold Leaf when Silver X Rays fall upon it.

Gas.	Density.	Temp.	$p_{\frac{1}{2}}$ Fast rays.	$p_{\frac{1}{2}}$ Slow rays.	λ Fast rays at 0° C., 76 cm.	λ Slow rays at 0° C., 76 cm.	λ/d Fast rays.	λ/d Slow rays.
Air	·00129	23° C.	7·36 cm.	1·77 cm.	5·35	22·25	4150	17250
O ₂	·00143	26° C.	7·05 „	1·53 „	5·64	26·00	3950	18190
CO ₂	·00198	23° C.	5·05 „	·90 „	7·80	43·76	3940	22100
SO ₂	·00293	22° C.	4·26 „	·91 „	9·21	43·2	3150	14720
Mean =							3797	18065

Ratio = 4·76

The mean value of λ/d for the fast rays approaches closely Lenard's probable value that I have calculated at the end of Part I, viz. 3120. As lending support to the conclusion that there are two distinct groups of particles present, "the experiments of C. T. R. Wilson* on the photography of the tracks of the emitted electrons in gases indicate that for monochromatic radiations they would consist of a limited number of definite lengths rather than a series extending from zero to an upper limit."†

On these grounds, I think that the present accepted values of the absorption coefficients in air and hydrogen for the fastest corpuscular rays ejected from a plate by silver characteristic rays will need modification.

* 'Proc. Roy. Soc.,' A, vol. xxxvii.

† O. W. Richardson, 'Proc. Roy. Soc.,' A, vol. xciv, p. 271 (1918).

I should like further to point out that each member of the second group of logarithmic curves begins to rise again very near to where $p = 0$, indicating the presence of a third group of corpuscles whose speed is less than that of the second group. Further, if the shape of the logarithmic ionisation density curves can be associated with Kaye's* logarithmic absorption (or rather selective transmission) curves, and if from further experiment accurate numerical relationships can be deduced as below as to the relative energies of sets of corpuscles liberated from a metallic surface, then great light will be thrown upon the mechanism of absorption by solids generally.

I have shown elsewhere,† from a theory put forward by Barkla,‡ viz. that for each quantum of energy absorbed there is emitted, if the wave-length is short enough, one high-speed electron together with quanta of K, L, radiations, etc., that in the region of an L absorption band the sudden fall in the constant of proportion between the absorption of energy per atom ionised and the fourth power of the atomic number of the absorber

$$= \frac{\nu_L + \nu_M + \dots}{\nu_M + \dots} = 4.8$$

if the absorber have an atomic weight approximately that of gold. ν_L, ν_M , etc., are the frequencies of X-ray spectra corresponding to the L, M, etc., emission lines of the absorber. It was for this reason that silver was chosen as radiator and gold as screen for emitting particles, for as the K wave-length for silver is intermediate between the K and L wave-lengths for gold, then only the L, M, etc., characteristic groups of particles would be produced. If the energies of the particles bore a simple relationship to the energy absorbed in their production, then it was presumed that the ratio of their absorption coefficients would be neither too great nor too small to be detected by this method.

(The corresponding ratio for K and L corpuscles from gold would probably lie between 7 and 8.)

It is perhaps too soon to draw any definite conclusions as to the exact processes involved, but I shall show that the ratio shown in Table II is not in conflict with the general photo-electric equation.

The fundamental law of photo-electric activity is $\frac{1}{2}mv^2 = h\nu - w$, in which $\frac{1}{2}mv^2$ represents the maximum kinetic energy of the liberated electrons, h is Planck's constant, ν the frequency of the exciting radiations, and w a constant which measures the work necessary to be done to get an electron out of the sphere of influence of the parent atom. Independent experiments of Hughes§ and Millikan|| have shown that the equation is valid so far as

* 'Phil. Trans. Roy. Soc.,' A, ccix, p. 137 (1919) ; also 'X Rays,' p. 126 (1917).

† 'Trans. Roy. Soc. S. Af.,' vi, Pt. 4, p. 321 (1917).

‡ 'Nature,' March 4, 1915, p. 7.

§ 'Phil. Trans.,' A, vol. ccxii, p. 205 (1912).

|| 'Phys. Rev.,' vol. vii, pp. 18, 355 (1916).

experiments with ordinary light are concerned ; but for X rays Richardson* says: "So far it has only been demonstrated as a limiting condition—that is to say, when matter is subjected to the action of radiation of frequency ν , no electron ever acquires a total energy, kinetic ($\frac{1}{2}mv^2$) and potential (w), in excess of $h\nu$." Very little is known about (w), which, according to Bohr, is the energy radiated away from the atom during the previous binding of the electron into it.

In the experiments hitherto made on the maximum speed of ejection of electrons by X rays, it follows that they must have come from the periphery of the atom. The important conclusion drawn, that v depended only upon ν and in no way upon the nature of the substance emitting the electrons, does not satisfy the complete photo-electric equation.

Whatever be the source of the ejected electrons in the case of X rays, it is indisputable from the experimental evidence at hand that for the highest speed electrons w must be very small compared with the other two terms. The very small variation in Beatty's absorption coefficients for the particles in air with variation of the nature of the metal of the screen from which they emerge, if the incident wave-length is constant, indicates the approximate truth of the last statement.

If the equation $\frac{1}{2}mv^2 = h\nu$ (where w is neglected) apparently holds good for all screens, it should be reversible. Identifying the kinetic energy of a particle with the product of its charge and the potential through which it has fallen, the experiments of Rutherford, Richardson and Barnes† show that this abbreviated equation is by no means true, but that there is a limiting frequency obtainable from a given target. Likewise Duane and Hunt‡ show that $Ve = h\nu$ accurately, over a small range of wave-lengths, their value of h being smaller by about 2 per cent. than Millikan's accurate value 6.55×10^{-27} , pointing to the possibility that a small constant negative term might be missing from the right-hand side of their equation.

The potential energy term in the photo-electric equation seems to acquire reality in the case of the slower group of electrons described herein. Their velocity should be given by—

$$\frac{1}{2}mv_{\text{slow}}^2 = A_{\text{g}}h\nu_{\text{K}} - A_{\text{v}}(h\nu_{\text{L}} + h\nu_{\text{M}} + \text{etc.}).$$

Putting $m = 8.9 \times 10^{-28}$ gm., $h = 6.55 \times 10^{-27}$ erg. sec., $A_{\text{g}}\nu_{\text{K}} = 5.855 \times 10^{18}$ (mean frequency of α , β , γ lines after Bragg), $A_{\text{u}}\nu_{\text{L}} = 2.538 \times 10^{18}$, $A_{\text{u}}\nu_{\text{M}} = \nu_{\text{L}\beta} - \nu_{\text{L}\alpha} = 417 \times 10^{18}$ ($A_{\text{u}}\nu_{\text{L}\beta} = 2.748 \times 10^{18}$ and $A_{\text{u}}\nu_{\text{L}\alpha} = 2.331 \times 10^{18}$ and $A_{\text{u}}\nu_{\text{L}}$ is taken as the mean of these) we obtain for the velocity of the slower corpuscle a value 65×10^8 cm./sec. If the missing terms of the equation were known, the velocity would be slightly less than this amount.

Now Thomson has shown on theoretical grounds that for these particles

* *Loc. cit.*

† 'Phil. Mag.,' [6] xxx, p. 352 (1915).

‡ 'Phys. Rev.,' [2] vi, p. 169 (1915).

diffusing through a gas the absorption coefficient varies inversely as the fourth power of their velocity,* whilst Whiddington came to a similar conclusion from experimental work.† I have shown that—

$$\frac{\lambda_{\text{slow}}}{\lambda_{\text{fast}}} = 4.76 = \frac{v_{\text{fast}}^4}{v_{\text{slow}}^4},$$

and therefore the maximum velocity of the faster corpuscle = 96×10^8 cm./sec. This speed according to Whiddington = $10^8 A$, where A is the atomic weight of the metal supplying the X rays—silver in this case. He makes the speed therefore 108×10^8 cm./sec. This, however, is too high. He has shown that the maximum velocity of a particle is not greater than the minimum velocity of the parent cathode particle originally producing the X rays. By interpolation from the results of Rutherford, Barnes, and Richardson, the velocity of the parent cathode particle produced silver X rays of mean frequency 5.855×10^{18} is 98×10^8 cm./sec., by extrapolation from the results of Duane and Hunt 92×10^8 cm./sec., and from the simple equation $\frac{1}{2}mv^2 = A_g(h\nu)_K$, 93×10^8 .

Further work with thin films of other metals and with different radiators is in progress.

SUMMARY.

Part I.—The absorption coefficients in air, O_2 , CO_2 and SO_2 of the secondary corpuscular rays from gold associated with the L, M, etc., characteristic radiations produced by the incidence of silver X rays upon it have been found by the “pressure variation” method. The results agree approximately with Lenard’s law and with Beatty’s values (‘Phil. Mag.’ [6] xx, p. 324, 1910) for air and H_2 . It is shown, however, that the absorption coefficients obtained by calculation from the pressure at which the cathode ionisation falls to half its maximum value are probably too high for the fastest corpuscles produced.

Part II.—To obtain as homogeneous a beam of particles as possible, a single very thin gold leaf was used as screen.

On carefully analysing the logarithmic cathode ionisation curves for the four gases, it was found that over a fair range each consists of a straight portion giving a logarithmic absorption coefficient for a faster group of particles, merging into a steeper curved portion rising to the axis $x = 0$, where x = distance from gold leaf, which was analysed with the help of the parent curve into a second straight portion giving a higher absorption coefficient than the first. The mean ratio of the two absorption coefficients is 4.76. It is suggested that at least two distinct groups of particles are present whose velocities from Thomson’s fourth power law, as verified

* ‘Cond. through Gases,’ p. 381 (1906).

† ‘Proc. Roy. Soc.,’ A, lxxxvi, p. 375 (1912).

experimentally by Whiddington ('Proc. Roy. Soc.,' A, lxxxvi, p. 375, 1912), are in the ratio of $4.76^{-\frac{1}{2}}$.

The maximum velocity of a corpuscle of the slower group, that associated with "L" characteristic radiation from gold, was calculated from the relationship—

$$\begin{array}{ccccc} \frac{1}{2}mv^2 & = & {}_{\text{Ag}}(h\nu)_{\text{K}} & - & {}_{\text{Au}}(h\nu_{\text{L}} + h\nu_{\text{M}} + \text{etc.}) \\ \text{Energy of ex-} & & \text{Quantum of incident} & & \text{Potential energy of particle within} \\ \text{pulsion.} & & \text{energy.} & & \text{the atom.} \end{array}$$

which gives a value 65×10^8 cm./sec., and therefore that of the faster corpuscle associated with "M" characteristic radiation from gold = 96×10^8 cm./sec.

Whiddington's value for this is 108×10^8 cm./sec. (maximum velocity of a corpuscle ejected by silver X rays), whilst the mean of the values of the velocity of a parent cathode particle producing silver X rays (series K) calculated from the results of Rutherford, Barnes, and Richardson ('Phil. Mag.' [6], xxx, p. 352, 1915), from Duane and Hunt ('Phys. Rev.,' vi, p. 169, 1915), and from $\frac{1}{2}mv^2 = {}_{\text{Ag}}(h\nu)_{\text{K}}$ is 96.5×10^8 cm./sec. In writing down the above formula it is assumed that only one quantum of incident energy is absorbed, and that the nearer a particle be to the nucleus of an atom the greater will be the energy required to bring it to the surface before expulsion.

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Read August 21st, 1918.